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Finite element analysis of non-axisymmetric stretch flanging process for prediction of location of failure

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Abstract

Stretch flanging is an important sheet metal forming process which is applied in automotive industry. In this paper, finite element simulation of stretch flanging process of AA 5052 has been carried out. It is found that both punch-die clearance and initial flange length has great effect on strain distribution and edge cracking along die profile radius. A good agreement has been obtained between results of simulation and experimental results, in terms of edge crack, punch load and punch stroke. From this investigation, finite element simulation is found to be quite useful in predicting deformation behavior of stretch flange quite efficiently.

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Keywords: Stretch Flanging;finite element simulation;punch-die clearance;initial flange length;edge crack;strain

1. Introduction

Flanging is one of the important processes of sheet metal forming which is used in automotive industry. Stretch flanging is one of the major types of flanging process. In stretch flanging tension is predominant along the top portion of flange and less near die profile radius in circumferential direction. Edge cracking is predominant mode of

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failure in stretch flanging. Previously studies have been carried on stretch flanging process by considering the effect of various geometrical and material parameters by researchers. Initial flange length is one of the major parameter of stretch flanging process. Influence of initial flange on circumferential strain along free edge has been studied in stretch flanging of V-shaped metal blanks using finite element simulation (Wang et al.,1984; Li et al., 2007).Prediction of strain and trimline has been investigated by using two different models for axisymmetric and non-axisymmetric stretch flanging process (Dudra et al.,1988).In another analysis of stretch flanging of Aluminum alloys by fluid forming fracture limit is determined which is found to be larger with increase in plastic strain ratio, strain hardening exponent and uniform strain (Asnafi1999).In stretch curved flanging the influence of length of straight side of flange, radius of curved range, flanging height and curvature radius of punch has been studied (Feng et al.,2004).Circumferential and radial cracking has been predicted in z-type stretch flanges of AA 5182 sheets using upper and lower bound damage-based material models (Butcher et al.,2006). Optimization of pre-form shape of blank size of stretch flange has been carried out using forward-inverse prediction scheme (Yeh et al.,2007).The objective of this study is to simulate non-axisymmetric stretch flanging process of 0.5 mm aluminum alloy 5052 for prediction of failure in terms of edge crack along die profile radius.

Nomenclature

c	punch-die clearance
D	ductile damage parameter
E	young's modulus
F	blank holding force
R	flange radius
R_d	die profile radius
L	initial flange length
l	length of straight portion
t	flange thickness/ sheet thickness
U	punch displacement
w	flange width
ρ	mass density
υ	poisson's ratio

2. Materials behavior

Uniaxial tensile testing of the aluminium alloy 5052 sheet has been prepared as per ASTM E8 standard and it is shown in the figure 2. The tensile samples are tested on a computerized universal testing machine INSTRON at a strain rate of 0.16667 per second for AA 5052 at room temperature along rolling direction. After testing the samples the following true stress-true strain curve is obtained as shown in figure 2 below. Table 1 and table 2 show the chemical composition and mechanical properties of AA 5052 of thickness (t) = 0.5mm.

Table 1. Chemical composition of AA 5052

Element	Si	Fe	Mg	Mn	Cu	Cr	Al
Wt.%	0.25	0.40	2.8	0.10	0.10	0.35	95.70

Table 2. Mechanical properties of AA 5052

Mechanical Property	Material AA 5052
Mass density (ρ)	2680 kg/m^3
Young's Modulus(E)	70.3 GPa
Poisson's ratio(υ)	0.33

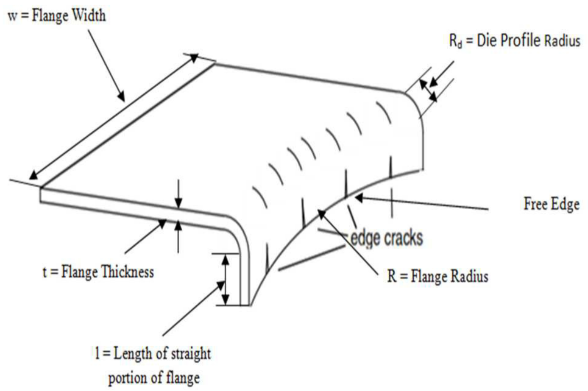


Fig.1. Definition of various portions of stretch flange

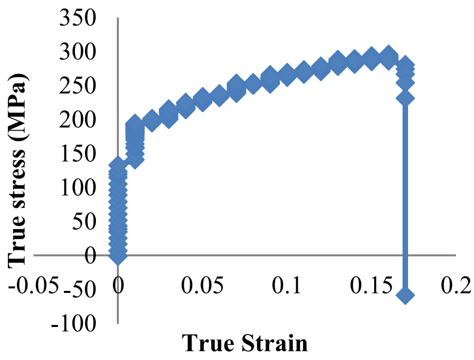


Fig.2. True stress-true strain curve for AA 5052

3. Finite Element Modeling

All the finite element simulations of the present stretch flanging tests were performed using finite element simulation software ABAQUS/Explicit V6.10. The ductile damage criteria and shear damage criteria are used for the initiation and propagation of edge cracking in the flange using damage evolution feature with element deletion technique. The element is deleted during simulation when ductile damage criteria and shear damage criteria are satisfied, when ductile damage parameter (D) becomes unity.

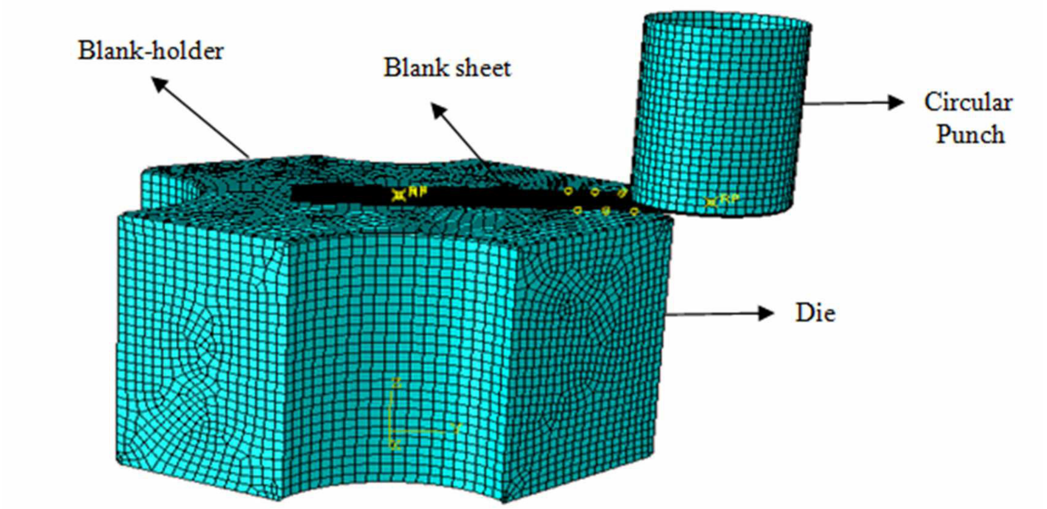


Fig.3. Finite element model of non-axisymmetric stretch flanging process

The punch, die and blank-holder are modelled with 4-noded bilinear quadrilateral discrete rigid 3D (R3D4) elements 1738 elements and 1765 nodes, 5883 elements and 5958 nodes, 1283 elements and 1356 nodes respectively. The dimensions of rectangular sheet metal blank of AA 5052 are 120 mm × 25 mm × 0.5mm.The rectangular sheet is modelled by using three dimensional C3D8R element type with 8500 elements and 17442 nodes with single layer through thickness direction. The present problem of non-axisymmetric stretch flanging process is a quasi-static problem which is solved in ABAQUS/Explicit using dynamic approach. The isotropic hardening rule with ductile damage (ductile damage criterion and shear damage criterion) is considered for AA 5052 during finite element simulation. The whole process of simulation has been carried in a single step of (t = 1 s).The experimental testing of stretch flanging is done at speed of 10mm/min while in simulation the above mentioned tested tensile properties of AA 5052 are used at a similar strain rate of 0.16667 per second. The die remains fixed during the whole process which is same as in experiments. A constant blank holding force of F= 20 KN is applied on the blank holder in all cases of simulation and experiment in order to take the change in thickness in to account. A gap of 1 mm between the blank-holder and the top surface of the sheet is given to avoid initial penetration during contact. The sheet remains free while punch is only allowed for vertical downward movement with the help of smooth type amplitude during the step.

4. Results of simulation and comparison

The concept given in the previous section is used for simulation of stretch flanging tests in ABAQUS V 6.10.The results are presented and compared in this section.

4.1. Parametric study

4.1.1. Effect of punch-die clearance

Punch-die clearance is one of the important parameter in the stretch flanging process which influences the process. Figure 4 shows the influence of punch-die clearance on circumferential strain along die profile radius. It is observed from the figure that circumferential strain diminishes along the die profile radius from edge upto a mid-position of sheet center and then increases upto sheet center. It is found from the figure that maximum and minimum circumferential strain occurs at the edge and at mid-position of center of sheet for all clearance at a common initial flange length of 3cm.It is also found that circumferential strain decreases by 14.61% at corner edge with increase in punch-die clearance from 1mm to 3 mm clearance at a common initial flange length of 3cm.

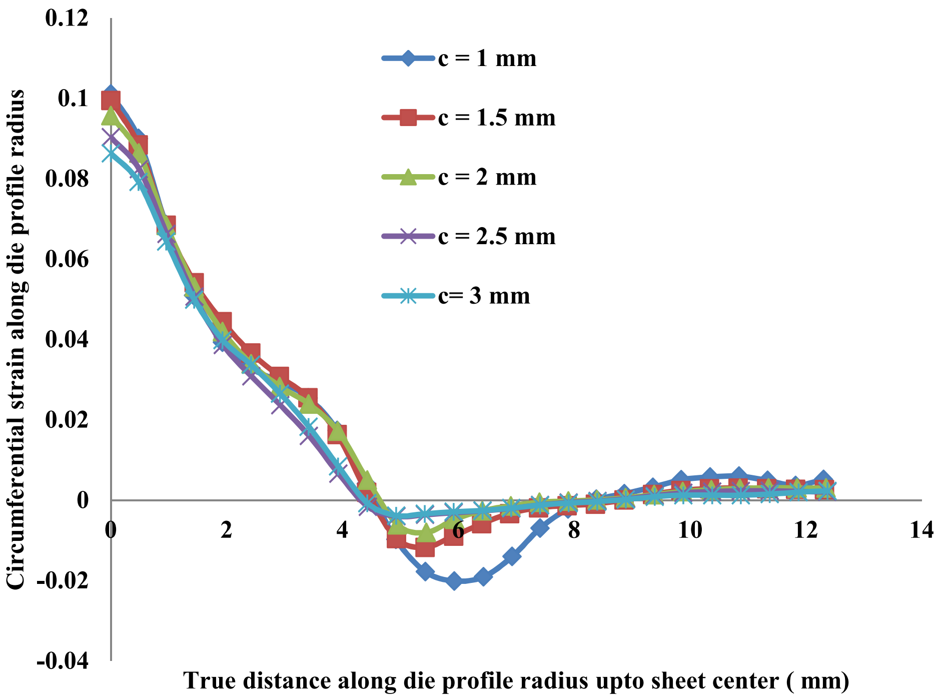


Fig.4. Effect of Punch-die clearance on circumferential strain

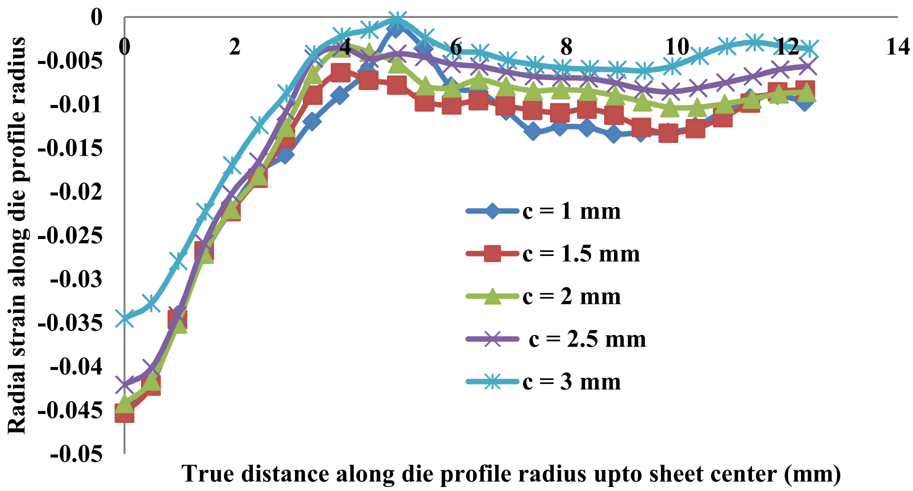


Fig.5. Effect of Punch-die clearance on radial strain

Figure 5 shows the influence of punch-die clearance on radial strain along die profile radius. It is observed from the figure that radial strain increases along the die profile radius from free edge up to a mid-position of sheet center and then decreases upto sheet center. It is found from the figure that maximum and minimum radial strain occurs at mid-position of center of sheet and at edge for all clearance at a common initial flange length of 3cm. It is also found that radial strain increases by 23.5 % at corner edge with increase in punch-die clearance from 1mm to 3 mm.

4.1.2. Effect of Initial flange length

Initial flange length is another important which significantly affects the formability of stretch flange. Figure 6 shows the distribution of radial strain along die profile radius for three different initial flange lengths. It is also observed from the figure that maximum and minimum radial strain occurs at a position near to the mid-position of the sheet center and edge of the flange along die profile radius. It is found that that radial strain increases by 1.25 % with increase in initial flange length from L = 2 cm to L= 4 cm at die corner edge.

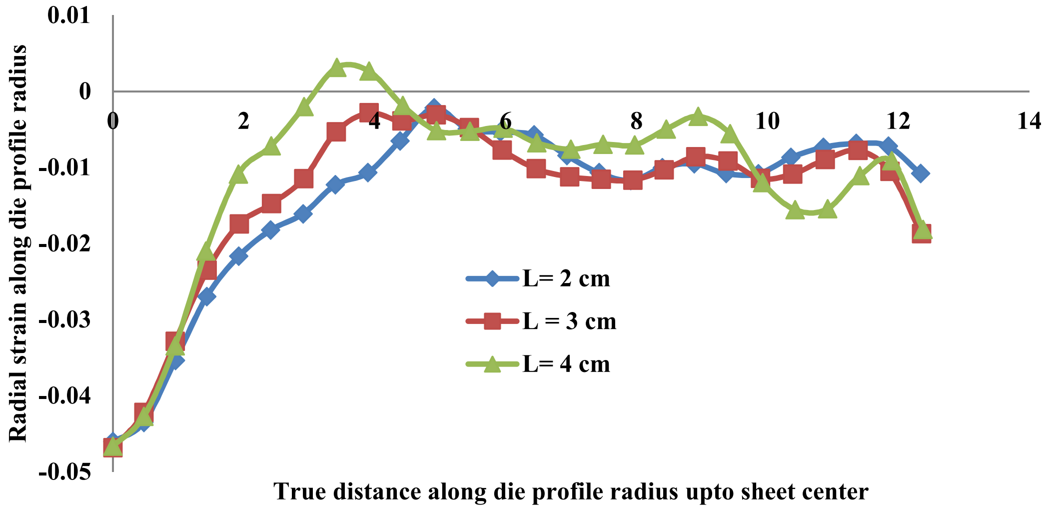


Fig.6. Effect of initial flange length on radial strain

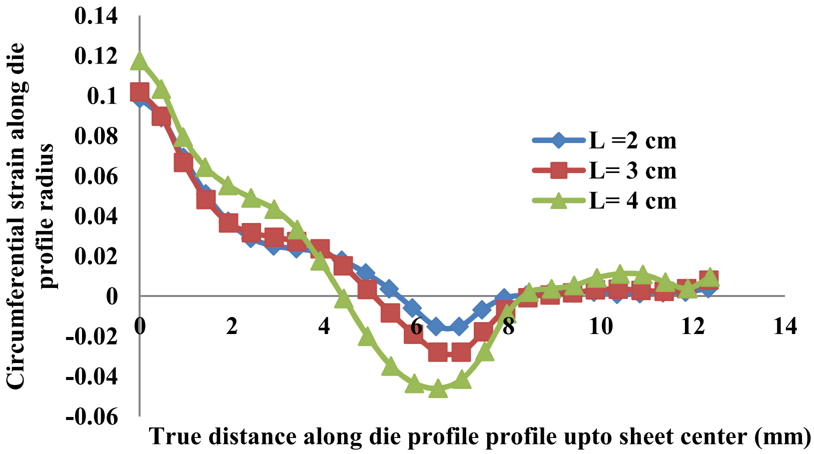


Fig.7. Effect of Initial flange length on circumferential strain

Figure 7 shows the variation of circumferential strain along die profile radius with initial flange length. It is observed from the figure that circumferential strain decreases along the die profile radius from edge upto a mid-position of sheet center and then increases upto sheet center. It is found from the figure that maximum and minimum circumferential strain occurs at the edge and at mid-position of center of sheet for all clearance at a common punch-die clearance of 1 mm .It is also found that circumferential strain increases by 19.14 % at corner edge with increase in initial flange length from 2 cm to 4 mm.

4.2. Comparison of simulation and experimental results

4.2.1. Comparison of edge crack location

4.2.1.1. Influence of punch-die clearance on edge crack

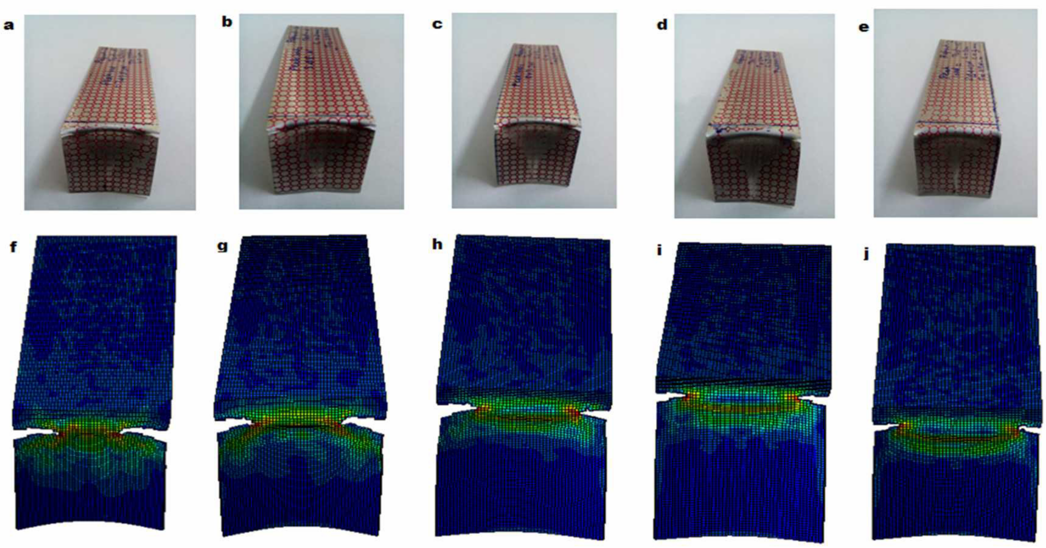


Fig.8. Comparison of edge crack location for different punch-die clearance between stretch flanging tests and simulation (a) experiment (c =1 mm) (b) experiment (c=1.5 mm) (c) experiment (c = 2 mm) (d) experiment (c = 2.5 mm) (e) experiment (c= 3 mm) (f) simulation (c=1 mm) (g) simulation(c=1.5 mm) (h) simulation (c = 2mm) (i) simulation (c= 2.5 mm) (j) simulation (c= 3 mm)

Figure 8 shows the comparison of location of edge crack which occurs during stretch flanging tests and in simulation for different cases of punch-die clearance from 1 mm to 3 mm at common initial flange length of 3 cm. It is observed that from the figures that crack originates from both ends position along die profile radius for all cases both in simulation and in experiment. Besides this, it is also found that crack length decreases both in simulation and in experiment with increase in punch-die clearance. In case of experiment the maximum crack length is observed in c =1 mm while no crack is observed in case of c = 3m, while on the other hand in simulation the crack length is also maximum in case of c = 1 mm and least for c =3 mm.It is found both from experiment and simulation that smaller will be the punch-die clearance higher will be the resulting circumferential strain which will actually lead to edge cracking along die profile radius. A good coincidence between results of simulation and experiment are obtained for the prediction of edge crack location.

4.2.1.2. Influence of initial flange length on edge crack

Figure 9 shows the comparison of location of edge crack which occurs during stretch flanging tests and in simulation for different cases of initial flange length from 2 cm to 4 cm at common punch-die clearance (c=1 mm). It is observed that from the figures that crack originates from both ends position along die profile radius for all cases. It is also found that crack length increased both in simulation and in experiment with increase in initial flange length since circumferential strain increases with increase in initial flange length, which will actually lead to edge crack along die profile radius. A good agreement between simulation and experiment is obtained for the prediction of edge crack location during the establishment of influence of initial flange length on edge crack along die profile radius.

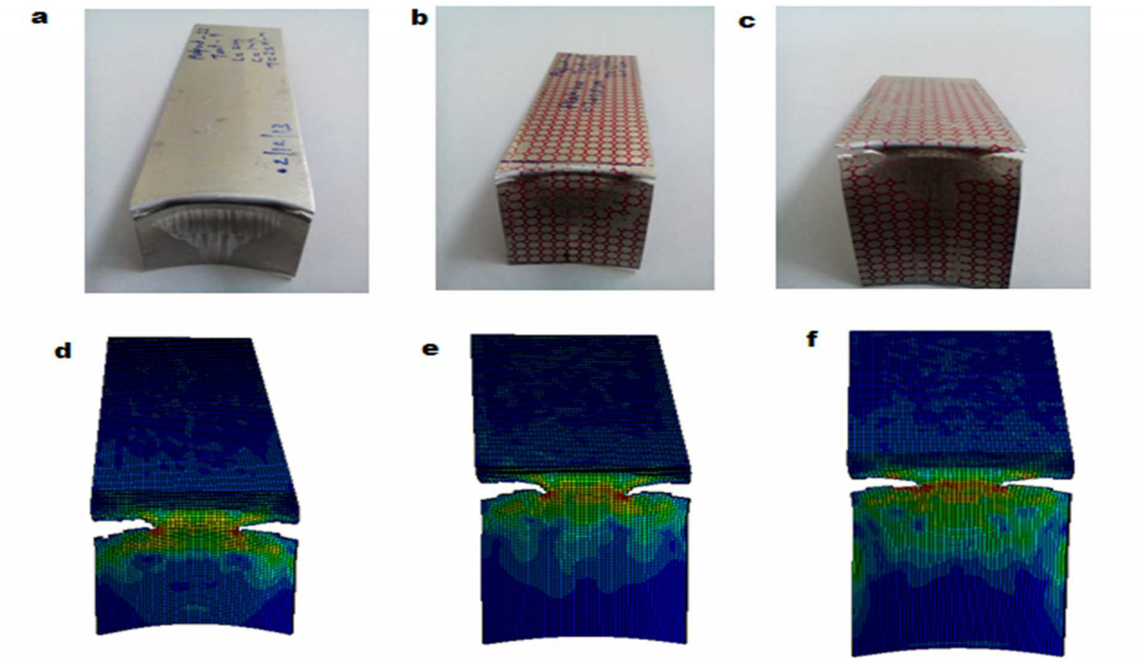


Fig.9. Comparison of edge crack location for different initial flange length between stretch flanging tests and simulation (a) experiment (L =2 cm) (b) experiment (c =3cm) (c) experiment (c = 4 cm) (d) simulation (L= 2cm) (e) simulation (L= 3cm) (f) simulation (L= 4cm)

4.2.2. Comparison of punch load

Figure 10 shows the comparison of punch load for stretch flanging tests for an initial length L = 3 cm at punch die clearance c = 1 mm with simulation. It is found from the figure that punch loads obtained from the simulation and from experiment shows a similar pattern of deformation.

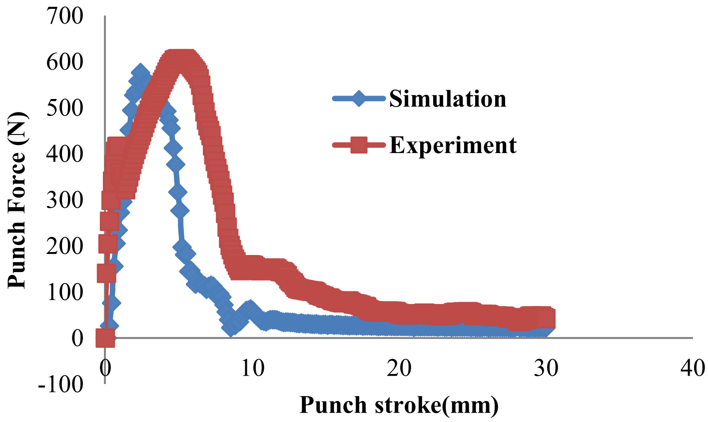


Fig.10. Comparison of punch load between simulation and experiment

4.2.3. Comparison of punch stroke

Figure 11 shows the comparison of punch stroke for stretch flanging tests for an initial length L = 2 cm with simulation. It is also found from the figure 12 that cracks initiation in simulation at punch displacement U = 5 mm has started in the case of simulation as ductile damage parameter (D) becomes 1 while in the experiment the crack initiation yet not started at U = 5 mm.It is observed from figure that with increase in punch stroke that edge crack along die profile radius increases both in simulation and experiment with increase in punch stroke in downward direction. A quite similar pattern is obtained for simulation and experiment for deformation of flange a various stages of punch-stroke.

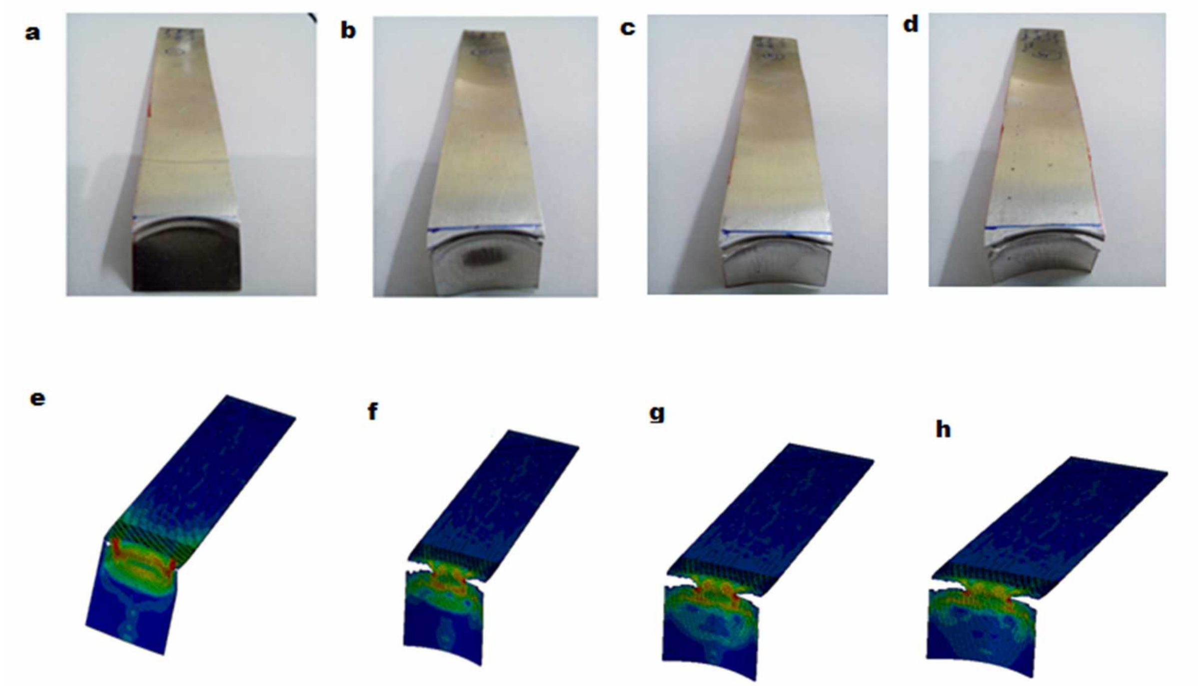
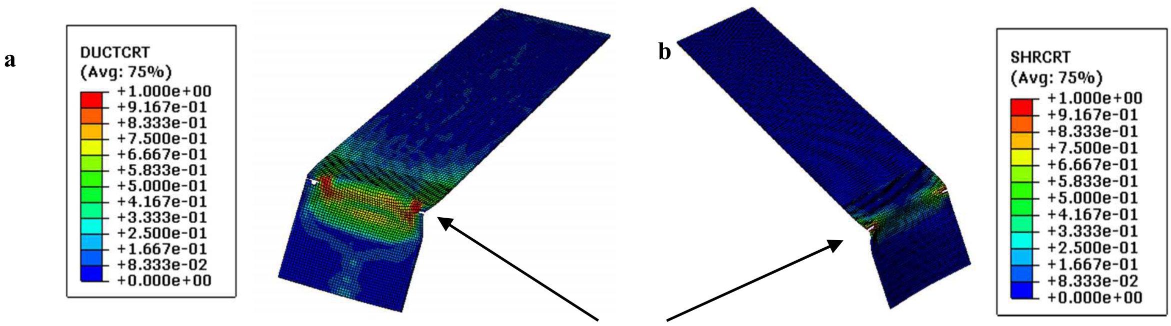


Fig. 11.Comparison of punch stroke between stretch flanging tests and simulation for a an initial length of 2cm (a) experiment (U= 5mm) (b) experiment (U= 10 mm) (c) experiment (U= 15 mm) (d) experiment (U= 20 mm) (e) simulation (U= 5 mm) (f) simulation (U= 10 mm) (g) simulation (U= 15 mm) (h) simulation (U= 20 mm)



Crack initiation in simulation

Fig.12. (a) Ductile damage initiation criteria with overall damage D = 1 at punch-displacement at U = 5 mm (b) Shear damage initiation criteria with overall damage D = 1 at punch-displacement U = 5 mm

5. Conclusions

In this paper the finite element model has been developed for analysis of non-axisymmetric stretch flanging. The following conclusion can be drawn:

[1] It is found that both punch-die clearance and initial flange length greatly influence strain distribution and edge cracking along die profile radius. Higher and lower the initial flange length and punch-die clearance respectively the higher will be the strain and edge cracking along die profile radius.

[2] It is found that a good agreement is obtained from comparison between simulated and experimental results such as prediction of location of edge crack, punch load and punch stroke.

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